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Effect of NaCl Concentration on Photosynthesis and Mineral Content of Barley Seedlings under Solution Culture

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ABSTRACT

This study was conducted to elucidate the changes of photosynthetic ability and cation content in barley cultivar seedlings cultured for 10 and 30 days with different NaCl concentrations containing 1/4 Hoagland solutions. At the highest NaCl concentration, the weight of dry matter and the shoot/root ratio (S/R ratio) were decreased. Thus, shoots were affected more than roots by NaCl treatment. The S/R ratio decreased more in 'Neulssalbori' than in 'Bunong' by the NaCl treatment. The internal Na^+ concentration increased greatly with the highest NaCl concentration, but K^+ concentration in plants decreased with the highest NaCl treatment. The Ca^{2+} concentration had a small change with NaCl concentrations. Thus Na^+/K^+ and Na^+/Ca^{2+} ratios increased with the highest concentration. The chlorophyll content (%/dry weight) of seedlings decreased at higher NaCl levels except for Bunong in 30 day old seedlings. The photosynthetic ability decreased only for Neulssalbori in the 10 days NaCl treatment. The stomatal conductance, and transpiration had decreased in the 10 day old seedlings, but not with 30 day old seedlings.

Key words **: barley, NaCl, Na^+, K^+, Ca^{2+}, chlorophyll, photosynthetic ability, stomatal conductance, transpiration.**

Salt-affected soils make up a substantial portion of the world's land area including approximately 33% of the irrigated soils (Marschner 1995). Much work has been done to control salinity by the physico-chemical methods such as reclamation, drainage, use of high leaching fractions, and application of soil amendments. At the same time, an approach to solve the problem has been applied to select and use plant species that are genetically more salt-tolerant. Selection and breeding for salt tolerance in a particular plant species could be facilitated if we could identify and understand the mechanisms of salt tolerance and sensitivity for that species (Greenway & Munns 1980, Cramer et al. 1985).

The inhibition of plant growth or development due to salinity is attributed to a decrease in water potential of the growing medium, ion toxicity and nutrient deficiency (Greenway & Munns 1980, Huang & Redmann 1995, Kim 1992). Low water potential in saline soils is attributed to decrease several physiological and biochemical processes such as enzyme activity, photosynthetic ability, and respiration (Brugneil & Lauteri 1991. Cho et al. 1995, Jolivet et al. 1990, Seemann & Critchley 1985). Therefore, high absorption of Na^+ and Cl^- in plants lead to reduced uptake of some essential elements such as K^+, Ca^{2+} and Mg^{2+}. so that plants may suffer severe nutrient starvation and finally die (Lynch & Laüchli 1984, Cramer et al. 1991).

Calcium can reduce the toxic effect of NaCl-salinity in barley as well as in other plants. Elevated Ca^{2+} levels may protect the plants from salt stress by reduction in leakness of cellular membranes, by reduction of Na^+ uptake and transport to the shoots, or by a combination of these effects (Cramer et al. 1985, 1987, 1991, Huang & Redmann 1995).

The objective of this study was to investigate the effects of salinity on the inorganic contents and the photosynthetic ability of the seedling of Korean barley cultivars.

MATERIALS AND METHODS

This experiment was conducted at the crop physiology laboratory of Chungnam National University in Korea using two barley cultivars; Neulssalbori (naked barley) and Bunong (hulled barley). The barleys were cultivated in 1/4 Hoagland solutions with four NaCl levels (0, 50, 100, and 150 mM) in a greenhouse for 10 and 30 days. Plants were grown under 12 h photoperiod of 250μM $m^{-2}s^{-1}$ photo flux density produced by a mixture of fluorescent and incandescent lights, with 27/22℃ temperature (day/night) and 70% relative humidity.

Sodium, potassium and calcium concentration were measured by Yoshida et al. (1972) method. These inorganic ions were extracted in 1N HCl at 30℃ for 24 hour after 100 mg of samples were dried at 80℃ for 7 days and analysed with an atomic absorption spectrophotometer (Baird Automic Ltd. Model Alpha 4).

The chlorophyll content of seedlings was measured by the method of Yoshida et al. (1972). The content of chlorophyll a , chlorophyll b, and total chlorophyll were measured with spectrophotometer (UV -120-02 Shimadzu) at 663 nm, 645 nm, and 652 nm, respectively. Photosynthetic ability, stomatal conductance and transpiration rate on the 1st leaf of barley seedling were measured with a portable photosynthetic meter (Licor Model LI-6200). The leaf area of 10 and 30 day old seedlings was measured with a leaf area meter (Licor Model LI-3100).

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RESULTS AND DISCUSSION

Dry matter

The dry matter of shoots and roots of barley seedlings cultured for 10 days and 30 days with different NaCl levels is shown in Figure 1. The growth of shoots and dry matter of shoots of 10 and 30 day old seedlings were reduced sharply with increasing NaCl levels, especially more than 100 mM NaCl. At 150 mM NaCl, the dry matter of 10 day old seedlings was 33% for the Neulssalbori cultivar and 29% for the Bunong cultivar lower compared to that of non-NaCl conditions. The seedling growth of 30 day old barley was reduced more severely than that of 10 day old barley. The dry matter of the two cultivars, Neulssalbori and Bunong, was only 63% and 52% respectively, compared to that of the non-NaCl condition.

On the other hand, dry matter of roots from 10 day old seedlings at different NaCl levels showed lower reduction compared to that of shoots (Fig. 1). While the root dry matter of 30 day old seedlings was different with the levels of NaCl, especially at the 100 mM and 150 mM NaCl levels. Under the 150 mM NaCl condition, root dry matter of both Neulssalbori and Bunong was about 50% and 42% less than that of non-NaCl condition. These results indicate that the reduction of dry matter of shoots in barley seedlings may be more severe for the naked barley (Neulssalbori) than for hulled barley (Bunong).

S/R ratio of barley seedlings was lower in NaCl-treated plants than that of the control (Table 1). The S/R ratio was generally reduced with increasing the concentration of NaCl in the medium. Similar results were reported by Munns & Termeat (1986), that leaf growth is more sensitive to salinity than root growth and by Shalhevet et al (1995) that salinity generally reduces shoot growth of plants more than root growth of the 12 species of plants.

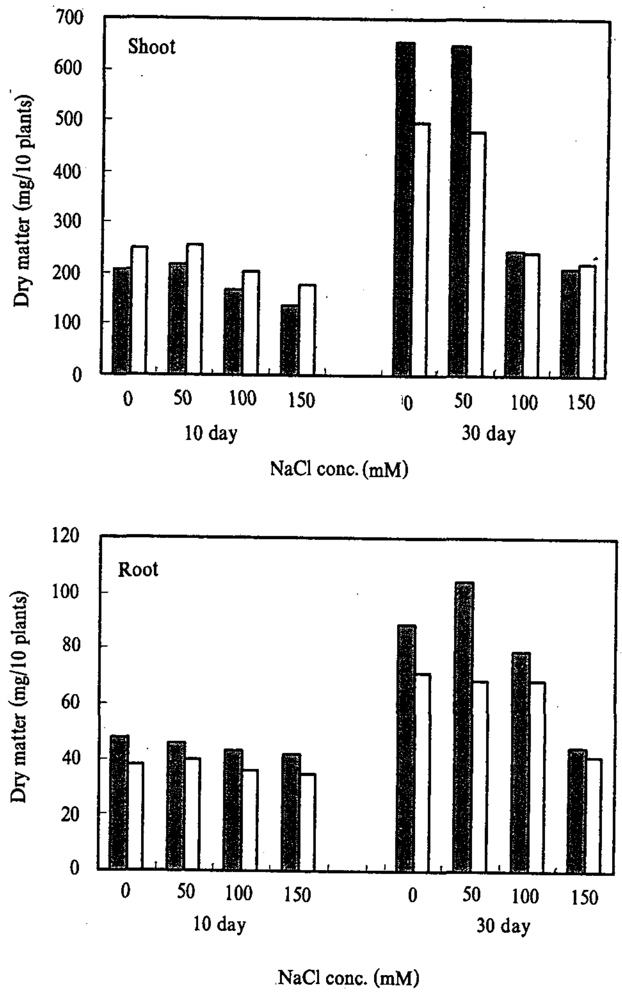

Fig. 1. Dry matter of barley (cv. ▧ ; Neulssalbori., □ ; Bunong) seedlings cultured for 10 and 30 days in different NaCl solution.

Content of sodium, potassium and calcium

Generally, the salt stress of plants is attributed to a decrease in water potential of growing medium, ion toxicity and nutrient deficiency because of accumulated and disturbed inorganic ions (Greenway & Munns 1980, Huang & Redmann 1995). Therefore, it could be managed a point salt-tolerant to salinity in internal inorganic content on plants such as Na^+, K^+, Ca^{2+} etc. Fig. 2

Table 1. Shoot/root ratio of 2 barley cultivar seedlings cultured for 10 and 30 days in different NaCl concentration in 1/4 Hoagland solution.

NaCl conc. (mM)	10 DAT†		30 DAT	
	Neulssalbori	Bunong	Neulssalbori	Bunong
0	4.3	6.6	7.4	7.0
50	4.8	6.5	6.2	7.0
100	3.9	5.7	3.1	3.5
150	3.3	5.2	4.7	5.4
Mean	4.1	6.0	5.4	5.7

† : Days after treatment.

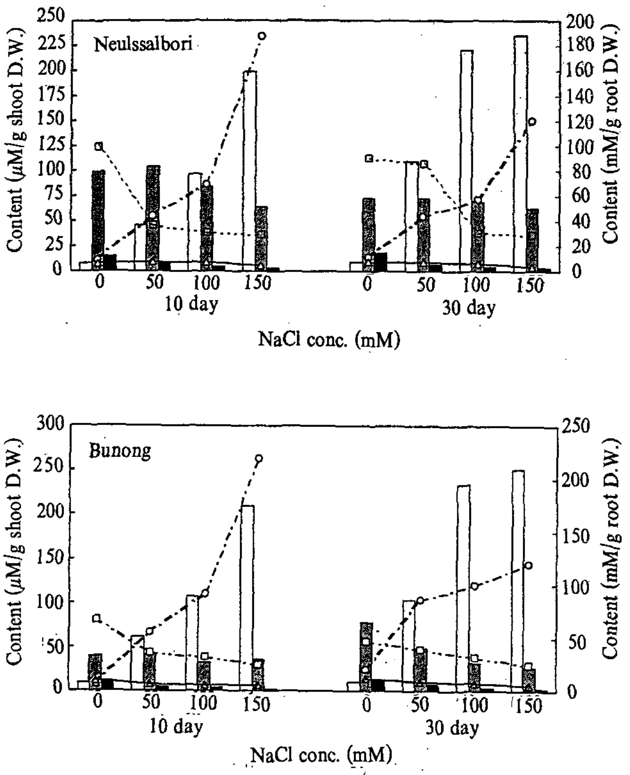

Fig. 2. Na^+, K^+, and Ca^{2+} content of barley seedlings cultured for 10 and 30 days in different NaCl solution. □ Na^+, ▨ K^+, and ■ Ca^{2+} is in shoot, ○⋯○ Na^+, □⋯□ K^+, and △–△ Ca^{2+} is in root.

shows Na^+, K^+, and Ca^{2+} contents of 10 and 30 day old barley seedlings with different NaCl levels. Internal Na^+ concentration increased rapidly with raising NaCl levels. In 10 day old seedlings of Neulssalbori, Na^+ concentration was higher in the root than in the shoot. However, in 30 day old seedlings, Na^+ concentration was higher in the shoot than in the root. Bunong had a similar result as Neulssalbori. Lower Na^+ concentration of roots in 30 day old seedlings than that of shoots could be assumed to be due to translocating the uptaken Na^+ toward shoot or efflux out constantly from absorbed Na^+ in root.

Potassium content of shoots was slightly decreased with increasing NaCl levels, while that of roots rapidly decreased at the 50 mM NaCl level in 10 day old seedlings. It is known that Neulssalbori cultivar has greater amount of K^+ than that of Bunong cultivar in non-NaCl conditions, but the inhibition rate of uptaking K^+ with treatment of NaCl in Nuelssalbori cultivar was higher than that of Bunong cultivar. Calcium content showed a similar tendency as the K^+ on NaCl stress in seedlings.

A high concentration of K^+ in plants is indispensable for metabolic processes and growth of plants. Therefore, Na^+/K^+ selectivity is an important factor in the salt tolerance of plants (Nakamura et al. 1990). Table 2 shows changes of the ratios of Na^+ to K^+ under different NaCl levels in barley seedlings. Generally, Na^+/K^+ ratios tended to increase either in NaCl-treated conditions rather than non-stressed or in roots rather than in shoots except for Bunong cultivar of 30 day old seedlings. These results, indicate that the high salinity uptake into plants inhibited the absorption and the translocation of K^+ because it might induce not only to reduce K^+ or Ca^{2+} activity but also to raise Na^+ activity in external solution.

The total content of the three cation (Na^+, K^+, and Ca^{2+}) increased with raising NaCl levels (Table 3). The total content of the shoots was higher than that in the roots of the two cultivars. Cramer et al (1991) reported that high concentrations of cations in the plant tissue may inhibit biochemical process and protein synthesis in the cytoplasm.

Effects of salinity to chlorophyll content, photosynthetic ability, stomatal conductance and transpiration

Total chlorophyll content decreased with higher NaCl levels in both 10 and 30 day old seedlings (Table 4). The decrease of 10 day old seedling was more in Neulssalbori than Bunong. However, in 30 day old seedlings the total chlorophyll content was similar in two cultivars. Also, the content of both chlorophyll a and b decreased with increasing the salinity.

The effects of NaCl stress on photosynthetic ability, stomatal conductance and transpiration per unit leaf area of seedling are shown in Table 5. The first leaf of

Table 2. Na^+/K^+ ratio of 2 cultivars barley seedlings cultured for 10 and 30 days in different NaCl concentrations.

NaCl conc. (mM)	10 DAT				30 DAT			
	Neulssalbori		Bunong		Neulssalbori		Bunong	
	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
0	0.08	0.09	0.24	0.14	0.13	0.12	0.13	0.69
50	0.44	1.17	1.49	2.07	0.51	0.52	2.12	2.15
100	1.14	2.26	3.29	2.74	3.19	1.88	7.26	2.89
150	3.15	6.49	5.90	8.17	3.74	4.17	9.52	4.58
Mean	1.20	2.50	2.73	3.28	2.14	1.67	4.76	2.58

Table 3. Sum of Na^+, K^+, and Ca^{2+} content of 2 cultivars barley seedling cultured for 10 and 30 days in different NaCl concentrations.

NaCl conc. (mM)	10 DAT						30 DAT					
	Neulssalbori			Bunong			Neulssalbori			Bunong		
	Shoot	Root	S/R	Shoot	Root	S/R	Shoot	Root	S/R	Shoot	Root	S/R
0	129.9	114.4	1.1	48.3	88.2	0.5	96.8	107.4	0.9	99.3	88.1	1.1
50	155.8	86.9	1.8	109.7	118.7	0.9	188.7	136.4	1.4	157.1	130.8	1.2
100	184.6	106.0	1.7	143.3	127.6	1.1	293.7	95.3	3.1	269.3	130.4	2.1
150	265.4	219.1	1.2	247.9	233.1	1.1	300.4	153.3	2.0	280.1	143.4	2.0
Mean	183.9	131.6	1.5	137.3	141.9	0.9	219.9	123.1	1.8	201.3	123.2	1.9

Table 4. Chlorophyll content (%/D.M.) of 2 cultivars barley seedlings cultured for 10 and 30 days in different NaCl levels.

NaCl conc. (mM)	10 DAT						30 DAT					
	Neulssalbori			Bunong			Neulssalbori			Bunong		
	a†	b‡	a+b	a	b	a+b	a	b	a+b	a	b	a+b
0	11.3	3.7	15.0	7.1	2.1	9.2	9.2	3.2	12.4	6.2	1.6	7.8
50	9.2	3.2	12.4	6.7	1.8	8.5	9.3	2.7	12.0	6.1	1.5	7.6
100	8.7	2.5	11.2	6.4	1.6	8.0	9.1	2.8	11.9	5.1	1.3	6.4
150	6.0	1.8	7.8	5.7	1.6	7.3	7.9	2.3	10.2	5.4	1.6	7.0
LSD(5%)	0.8	0.3	0.7	0.7	0.4	1.1	1.2	0.2	1.4	0.7	0.5	0.7

† ; chlorophyll a, ‡ ; chlorophyll b.

Table 5. Photosynthetic ability (μ mol $m^{-2}s^{-1}$), stomatal conductance (mol $m^{-2}s^{-1}$) and transpiration (m mol $m^{-2}s^{-1}$) of 2 cultivars barley seedlings cultured for 10 and 30 days in different NaCl solutions.

NaCl Conc. (mM)	10 DAT						30 DAT					
	Neulssalbori			Bunong			Neulssalbori			Bunong		
	P†	S	T	P	S	T	P	S	T	P	S	T
0	4.69	0.98	22.0	4.57	0.88	19.1	4.73	0.76	19.3	4.65	0.90	16.7
50	4.61	0.83	19.8	4.58	0.75	16.5	4.73	0.61	18.2	4.60	0.79	18.3
100	4.57	0.82	18.3	4.60	0.70	15.0	4.80	0.59	17.9	4.55	0.71	18.1
150	4.36	0.78	17.5	4.58	0.65	13.6	4.70	0.68	19.9	4.70	0.65	17.8
LSD9(5%)	0.13	0.08	1.30	0.10	0.09	1.87	0.16	0.08	1.26	0.19	0.06	1.46

† P ; photosynthetic ability, S ; Stomatal conductance, T ; Transpiration.

seedlings was used to measure the photosynthetic ability. NaCl treatment did not decrease the photosynthetic ability of first leaf except for the Neulssalbori of 10 day old seedling. Lee et al. (1996) reported photosynthetic ability per cm^2 in first leaf was not affected by NaCl concentration of 1/2 Hoagland solution. Robinson et al. (1983) also reported that salt stress did not result in any major decrease in the photosynthetic potential of spinach leaf and pothosynthesis may be reduced by other factors such as decreased leaf area. Seemann & Critchley (1985) reported that salinity had little effect on the total nitrogen and ribulose-1,5-bisphosphate carboxylase content per unit leaf area in *Phaseolus vulgaris* L.. Therefore, salinity had little effect on the photosynthetic ability per unit leaf area in barley seedlings. This result indicates that plants may be inhibited for a short time response by the salinity but they resist probably by salt tolerant revolution with progressing growth and development of a stressed plants. However, salt-stressed plants reduce growth due to lower leaf area, retardation of leaf emergence rate, reduction of leaf tissue cells, and increase of respiration (Cramer et al. 1991, Munns & Termeat 1986, Lee et al. 1996, Schanchtman & Munns 1992). On the other hand, stomatal conductance and transpiration decreased in 10 day old seedlings but not in 30 day old.

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